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# A reflectometer unit for a 500 kW HF balanced screened feeder

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Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

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# A REFLECTOMETER UNIT FOR A 500 kW HF BALANCED SCREENED FEEDER

**R.D.C. Thoday, C.Eng., M.I.E.R.E.**

**Summary**

*A test reflectometer has been produced for use on 500 kW high frequency (h.f.) senders in conjunction with a commercially-produced 750 kW soda load. The unit has been designed for monitoring purposes and calibrated so that known matched and mismatched load conditions can be applied to a sender under test.*

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Head of Research Department

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## A REFLECTOMETER UNIT FOR A 500 kW HF BALANCED SCREENED FEEDER

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## 1. Introduction

New 500 kW h.f. senders[1] are currently being installed at the Rampisham short-wave transmitting station. As part of the facilities for these senders, a 750 kW balanced line test load has also been installed. The load is designed for continuous dissipation using a soda*- solution column as the broad-band resistive element. The resistance of the soda solution is temperature dependant and relies on a thermostatic control valve and heat exchanger to maintain a constant mean temperature, and therefore constant resistance, while in use. However, the operational requirements for this load are that it can be used under both matched and calibrated, mismatched conditions. For this purpose a test reflectometer was requested by the External Services of the BBC.

At BBC h.f. transmitting stations a balanced-feeder system is generally used between the sender and the aerial arrays, and it is current practice to enclose the feeders in metal trunking. This has the advantage of reducing extraneous fields, particularly in the vicinity of the transmitter buildings, and in reducing coupling between adjacent feeder systems.

However, the addition of screening around the balanced conductor increases the attenuation due to skin effect although, in practice, this will probably be balanced against the reduction of loss due to radiation from the feeder.

The latest sender designs use a single-ended tetrode-valve output stage with unbalanced output circuits and a co-axial output feeder system. The transition between unbalanced and balanced feeder systems is performed using wide-band baluns with tapering feeder lines to give the requisite impedance transformation.

Screened balanced-feeder systems have been in use with 100 kW and 250 kW senders over a number of years and h.f. reflectometers for balanced feeders, providing executive control, have been built to a BBC Research Department design[1] for overseas transmitting stations at Tebrau and Antigua. It was decided that the base-plate design of those reflectometers should form the basis for the monitoring equipment for the larger-dimensioned feeder of the test load.

* i.e. sodium carbonate.

1 the term traditionally used for h.f. transmitters.

## 2. General requirements for the reflectometer

The reflectometer is required to operate over the h.f. frequency range 4-26 MHz, and to be usable for monitoring purposes up to 100 MHz, on a balanced-feeder system of about 320 ohms characteristic impedance.

In the h.f. band, forward and backward power measurements are required for the balanced transmission mode, so that known mismatches can be applied as a load to the sender during acceptance tests and performance trials. The reflectometer may also be required for determining the actual balanced load impedance. In the extended frequency range 26-100 MHz it is required for monitoring the harmonic levels from the sender output.

An unbalanced coupler has also been included so that forward unbalanced power levels can be monitored.

The basic specification that has been achieved is as follows: –

Balanced Mode

Combined balanced-mode couplers (with equalisation)

| | | |
|---|---|---|
| output ratio | $-75.3\,\text{dB} \pm 0.2\,\text{dB}$ | (4 – 26 MHz) |
| | $-75.3\,\text{dB}\ {}^{+0.2\,\text{dB}}_{-1.5\,\text{dB}}$ | (3 – 100 MHz) |
| directivity | $\geqslant 34\,\text{dB}$ | (4 – 26 MHz) |

Screened feeder characteristic impedance, $Z_o$ = 321 ohms.

Unbalanced Mode

Unbalanced-mode coupler

| | | |
|---|---|---|
| output ratio | $-77.5\,\text{dB} \pm 0.2\,\text{dB}$ | (4 – 26 MHz) |
| | $-77.5\,\text{dB}\ {}^{+0.2\,\text{dB}}_{-2.5\,\text{dB}}$ | (3 – 100 MHz) |
| directivity | $\geqslant 26\,\text{dB}$ | (4 – 26 MHz) |

Screened feeder characteristic impedance, $Z_o$ = 84.8 ohms.

## 3. Description of the equipment

The screen of the balanced line used for 500 kW sender installations is made up from 2.0 m long trunk sections fabricated from aluminium sheets. The upper part of the screen is made from sheets bolted together into an inverted u-shape with end flanges for connection to adjacent sections. A flat sheet with flanges provided on all edges is fitted into the upper part as a baseplate, to form a rectangular cross-section screen of internal dimensions 375 mm by 762 mm. The balanced line conductors, 28 mm diameter copper tubes spaced 380 mm between centres, are supported by 45 mm diameter p.t.f.e. insulators mounted on the baseplate.

The reflectometer is made up as a short panel baseplate and is fitted with the balanced-line support insulators. The baseplate is fitted with five directional couplers; these comprise two forward and two backward balanced-mode couplers, positioned below the balanced-line conductors, and a single centrally placed unbalanced-mode coupler. The output ratio of the couplers has to be high (at least 50 dB) so that the maximum coupled power can be conveniently handled. The baseplate is shown in Fig. 1. The couplers are fabricated from brass strips and are terminated in 50 ohm 5W loads. The output ports are fed to passive equalisers mounted in screened boxes on the underside of the baseplate as shown, with top covers removed, in Fig. 2.

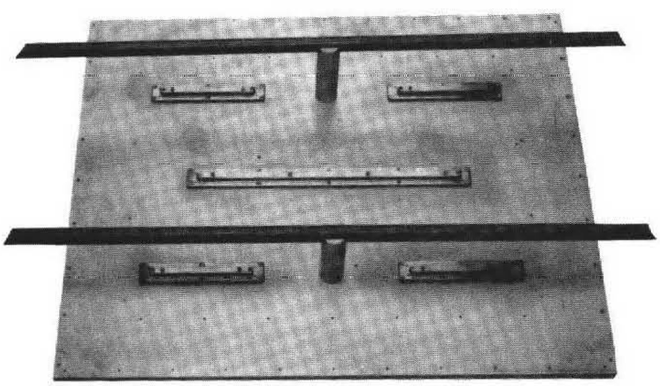


*Fig. 1 – The baseplate fitted with directional couplers.*

As the reflectometer baseplate is shorter than the standard length panel, sub-panels have been added at each end of the baseplate to complete the screening of the line. These use standard thickness materials while that of the reflectometer baseplate is of a heavier gauge to maintain rigid support for the couplers and line conductors.

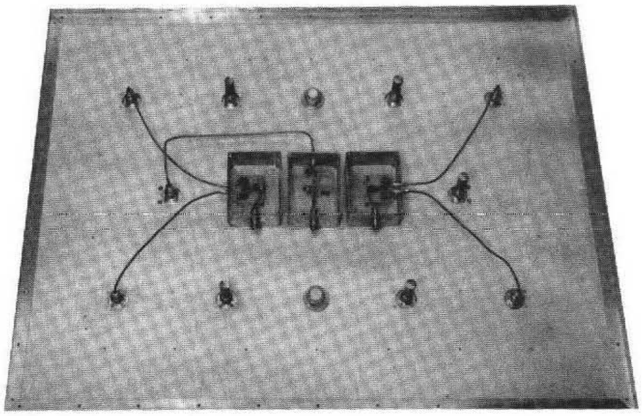


*Fig. 2 – The underside of the baseplate showing the passive equalisers and the directional coupler terminating loads.*

## 4. Measurement methods

The most important requirement for the directional couplers is to obtain a high directivity. To set them up, it is essential that the main transmission-line is properly matched. Once this has been achieved, successive adjustments of the coupler spacing and dimensions can be made until the wanted directivity has been reached. Methods of checking the impedance match of the transmission line are by measuring the standing-wave ratio (s.w.r.) along the line, by impedance bridge measurements, or by the use of a time-domain reflectometer. The latter requires a test line long enough to give adequate delay between the transmitted and reflected pulses to enable accurate relative amplitude measurements to be made. Only 8 m of test line was available for these measurements and this was considered too short for this purpose; a further complication is obtaining an instrument designed for operation on balanced, high characteristic-impedance lines. The impedance bridge method tends to be difficult in practice because of inaccuracy in the bridge itself and possible errors due to discontinuities between the bridge and the lines, but it is probably an acceptable method for the lower end of the frequency range.

The standing-wave measurement method can provide accurate results but is somewhat tedious in execution on a screened line. Two variants of this method have been used for these measurements. The first was by drawing a wheeled trolley, constructed mainly from glass-fibre tube and carrying a short horizontal dipole and balun transformer, along the line. It is important for the coaxial feeder carrying the output from the balun transformer to be carefully positioned so that

stray pick-up of the field within the trunking is minimised. The feeder was suspended vertically downwards from the balun transformer and pulled along with the trolley as it lay aligned along the central plane between the main-line conductors on the surface of the trunking baseplate, where the electric field is at a minimum. This method was reasonably quick in operation, but errors occurred due to misalignment of the dipole element, the trolley not running centrally on the conductors and (although small in effect) the perturbation of the line itself.

An alternative method used was to drill a series of holes along the length of the trunking so that a small probe could be inserted into the screened volume and in close proximity to one of the line conductors. The probe, a rigid length of co-axial feeder with its inner conductor exposed for approximately 5 mm was positioned near to one of the conductors. By the use of a dielectric shroud a fixed separation of about 20 mm could be ensured between the probe inner and line conductor once the shroud had made contact with the conductor. This method was slow but gave repeatable results.

#### 4.1. Setting up of the test line load and measurement of the balanced coupler directivity

The test transmission line was terminated in a balanced load made up from five carbon-film resistors assembled in the form of a truncated V. A tapering screensheet was formed around the exterior periphery of the resistor chain, to improve the bandwidth of the load. The central load resistor was short-circuited to the screensheet at its midpoint and two variable resistors were added between the connections with adjacent resistors and ground. Trimmer capacitors were added across the load to give fine adjustments to the load impedance.

With the line driven from a balanced source, the load impedance was adjusted until the ratio of outputs from the forward and backward couplers gave an apparent directivity in excess of −50 dB, i.e. the reflection co-efficient was ≤0.3%. The standing-wave ratio on the main-line conductors was then measured using the trolley or test probe and the reflection coefficient $\rho_{\text{line}}$ of the test line calculated.

The directivity of the couplers can be taken as not worse than 20 $\log_{10}$ $(\rho_{\text{line}} + \rho_c)$, where $\rho_c$ is the measured reflection coefficient obtained from the forward and backward coupler measurements. The first measurements showed inadequate directivity; the coupler conductor spacing was therefore changed and the test-line load readjusted for maximum ratio of outputs from the couplers. This was repeated until a satisfactory figure had been obtained for the directivity. Once this had been achieved at midband the directivity was determined at other frequencies in a similar manner without further adjustment to the coupler dimensions.

Measurements were also made with a standing-wave ratio of 1.5:1 on the test line. The measured value of reflection coefficient from the couplers and calculated value from the standing-wave ratio were compared. Here, attempts were made to set the phase of the reflection coefficient by changes in the main-line load so that the greatest error between measured and calculated reflection coefficient for a given s.w.r. was obtained. The difference between the calculated and measured results gave the figure for minimum directivity. At the lower frequencies the impedance match was measured using an admittance bridge, because the length of the line was too short for both the maximum and minimum of the standing-wave to exist along its length.

#### 4.2. Measurement of coupling coefficient

Measurements were made using a vector voltmeter with the reference probe connected across one half of the test-line load, i.e. between one conductor of the balanced line and ground, and with the test probe measuring the output from the forward-wave coupler. The test-line load was adjusted to give minimum ouput from the backward couplers; it was necessary to resonate the self capacitance of the probe across the test-line load with a shunt inductance to do this. The relative output from the forward-wave coupler was then measured using the test probe of the vector voltmeter connected across the 50 ohm termination.

Using this method the outpt ratio in decibels is:

$$20\log_{10}\ (V_{\text{test}}/2\ V_{\text{ref.}}) + 10\ \log_{10}\ (Z_o/50)$$

Formulae for the characteristic impedance, $Z_o$, of the shielded line are given in Appendix; the value for this line driven in the balanced-mode has been computed as 321 ohms.

As a check on the results obtained by the previous methods, the balanced resistive load was replaced by a λ/2 line balun terminated with

50 ohms. The line was thus presented with a 200 ohm impedance and was therefore mismatched with standing-waves present. The output ratio of the forward coupler was again measured directly with the vector voltmeter but a correction for loss of forward power due to the reflection at the load was also necessary. The reflection coefficient was obtained by measurement of the outputs of the forward and backward wave couplers.

The output ratio (in decibels) under these conditions is:

$$20 \log_{10} \ (V_{\text{test}}/V_{\text{ref.}}) + 10 \log_{10} \ (1 - \rho^2)$$

The expected error using this method depends upon the directivity of the coupler; with a 200 ohm load $\rho \simeq 23\%$ and with a coupler directivity of say, 34 dB, the measured reflection coefficient would be in the range $\rho \pm 2\%$, giving a loss correction term (second term in the above expression) of 0.24 ± 0.04 dB, showing a maximum error of 0.04 dB is possible in the results. These measurements were performed between 4 and 30 MHz.

## 5. Equalisation of the coupler output ratio

The maximum output from the couplers is at the high frequency end of the band as shown in Fig. 3. With a 500 kW power flow along the main feeder, the expected power coupled into each coupler at 26 MHz is −51.4 dB i.e. ≃ 4 watts. This must be tolerated by the terminating loads of the backward-wave couplers and in the equaliser of the forward-wave couplers. If matching resistive loads were used in the equaliser this would require that the necessary balun transformer should be capable of passing twice this power to the equaliser. To avoid this, the equalisers were designed as reactance loads so that power coupled to the output port is largely reflected. This allows the use of a single, medium-sized, co-axial terminating load for each of the couplers. A circuit diagram of the equaliser is shown in Fig. 4(a); it will be seen that it serves also to combine the outputs of a pair of forward (or backward) couplers.

The series capacitors are used to improve the low-frequency response of the units and permit a reduction of insertion loss to be made over the band.

The corresponding equaliser for the unbalanced-mode coupler is shown in Fig. 4(b).

## 6. Measured results: balanced couplers

The combined coupler plus equaliser output-ratio characteristics are shown in Figs. 5(a) and 5(b). Fig. 5(a) shows the measured characteristics over the h.f. band in detail, which have been obtained using the methods of measurement described in Section 4. In Fig, 5(b) these results

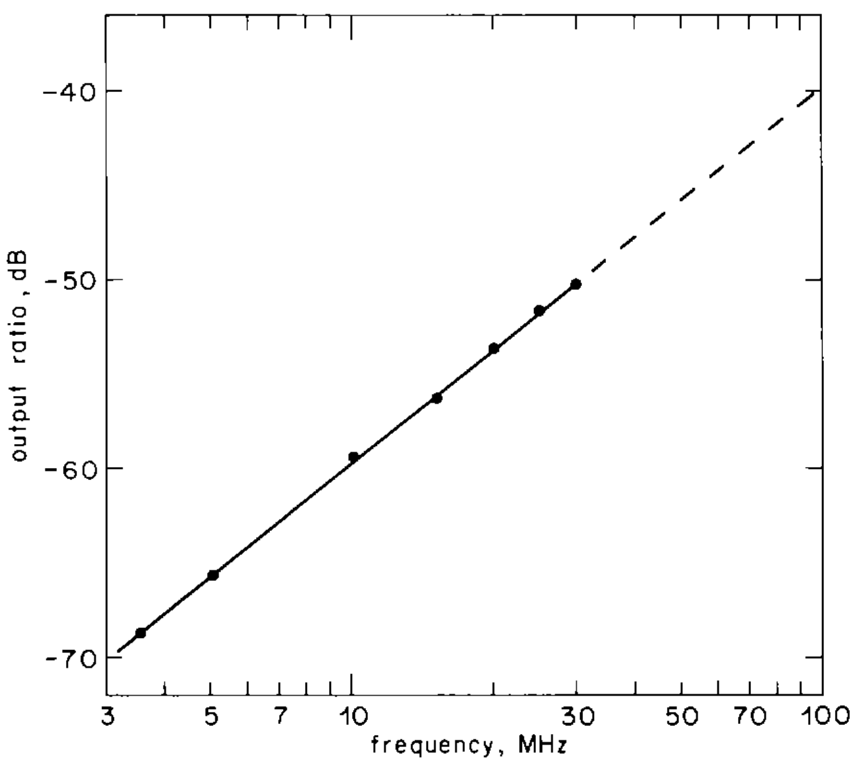



*Fig. 3 — Output ratio of balanced-mode couplers.*

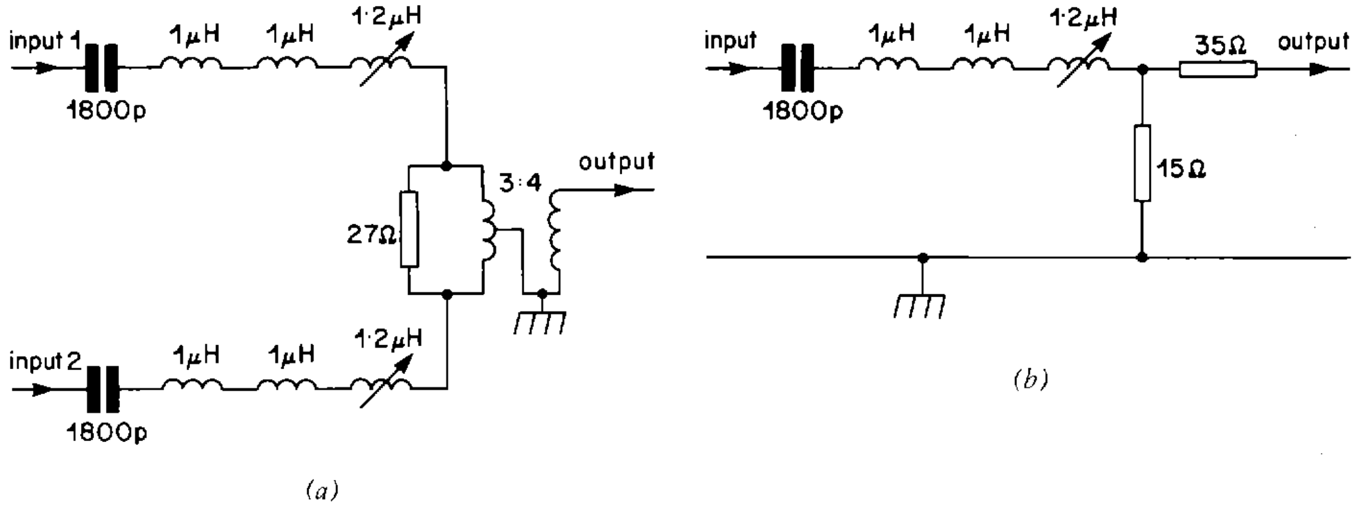



*Fig. 4 — (a) Circuit diagram of the balanced-mode coupler equaliser. (b) Circuit diagram of the unbalanced-mode coupler equaliser.*

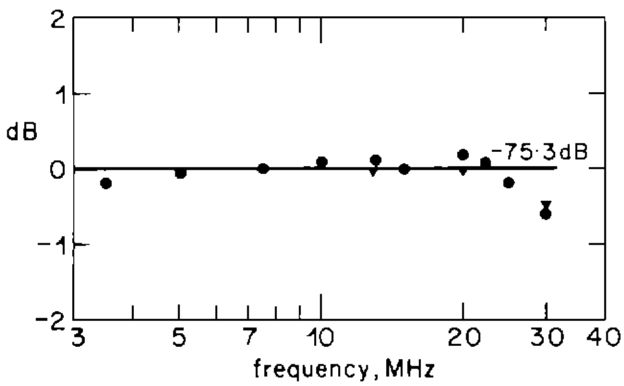



*Fig. 5(a) — Variation in output ratio of balanced-mode couplers (with equalisation) over the frequency range 3.0 MHz to 30 MHz.*

- ● *resonant probe method*
- ▾ *λ/2 balun measurements*

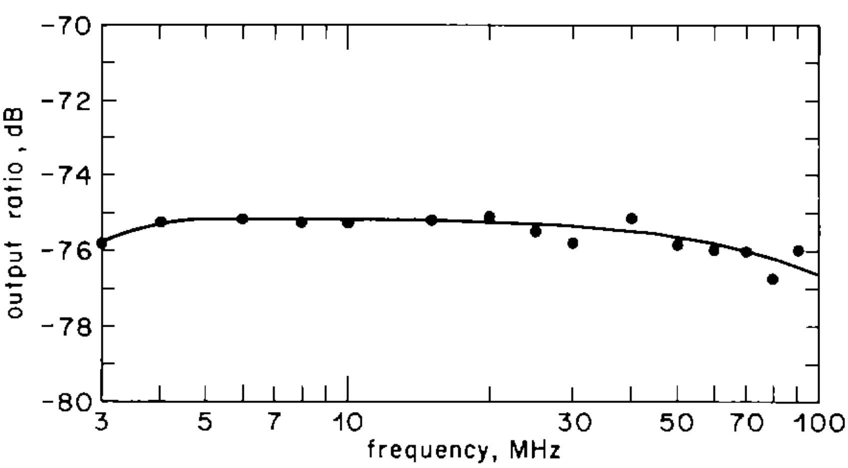



*Fig. 5(b) — Output ratio of balanced-mode couplers (with equalisation) over the frequency range 3.0 MHz to 100 MHz.*

have been augmented to extend the characteristic to 100 MHz. This has been achieved first by assuming that the output of the coupler itself would rise to 6 dB per octave and then by measuring the difference between the output of a single balanced-mode coupler and that of an equalised pair of balanced-mode couplers, adding a correction term to the results. The correction comprises the known rise in coupler output with frequency plus a constant to make these results consistent with those at the lower frequencies obtained by other methods of measurements.

The estimated minimum directivity of a balanced coupler from all measurements is shown in Fig. 6. The relative amplitude and phase response of the forward and backward couplers with equalisers is shown in Fig. 7. These measurements were obtained using both pairs of couplers as forward-wave couplers. A length of co-axial feeder was used to compensate for the phase difference between the forward and backward coupler outputs owing to the difference in their positions along the line.

## 7. Measured results: unbalanced coupler

The methods of measurement used to determine the directivity, output ratio and equalisation characteristic of the unbalanced coupler and equaliser, were similar to those used for the balanced-mode couplers.

The wheeled trolley could not be used for s.w.r. measurements, however, because of excessive pick-up on the output feeder attached to the balun transformer on the trolley. The test probe inserted through the screen-wall drillings was used for these measurements.

In making the coupling measurements, the test line was driven in the unbalanced mode, i.e. with the inner conductors paralleled giving a $Z_0$ = 84.8 ohms and was terminated with a 50 ohm impedance co-axial cable connected to the vector voltmeter reference probe and a 50 ohm load. The relative output power at the load and coupler could be measured over the whole frequency range. The output ratios of the coupler and the coupler

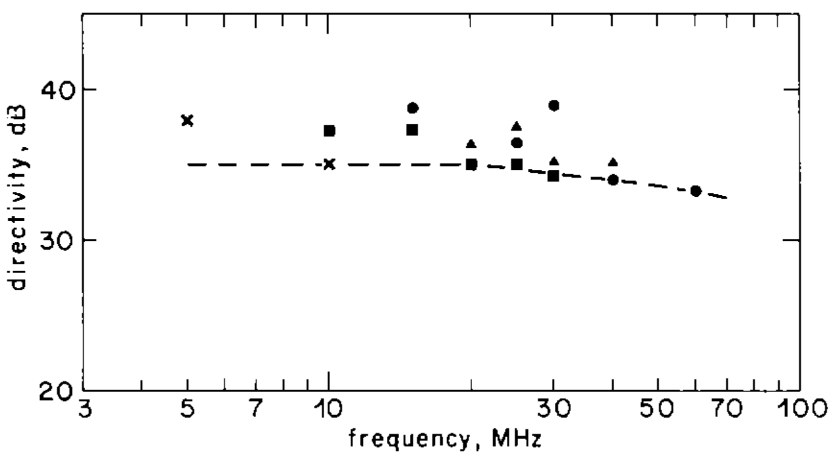



*Fig. 6 — Minimum directivity of the balanced-mode couplers.*



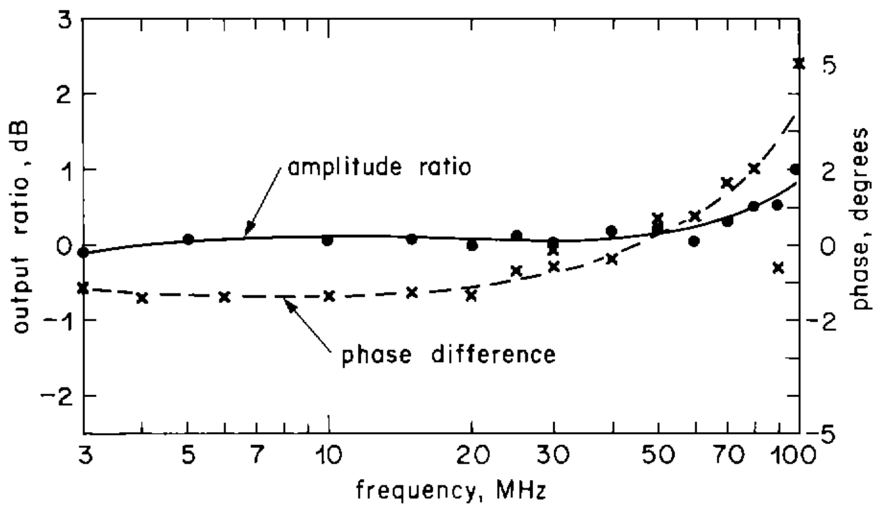



*Fig. 7 — Variation in output ratio and phase difference between equalised forward and backward balanced-mode directional couplers.*

Fig. 8 — *Unbalanced-mode coupler output ratio.*

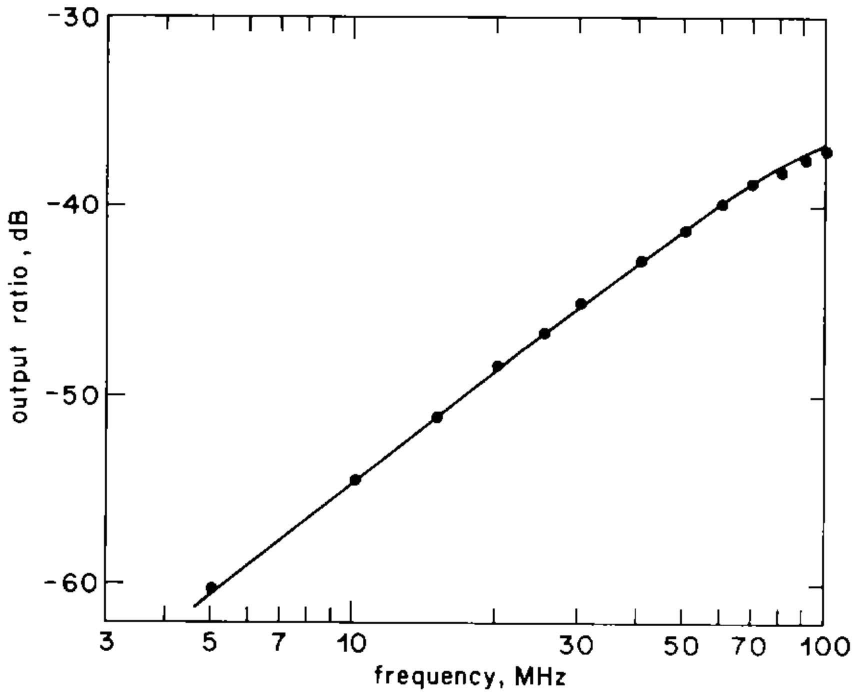
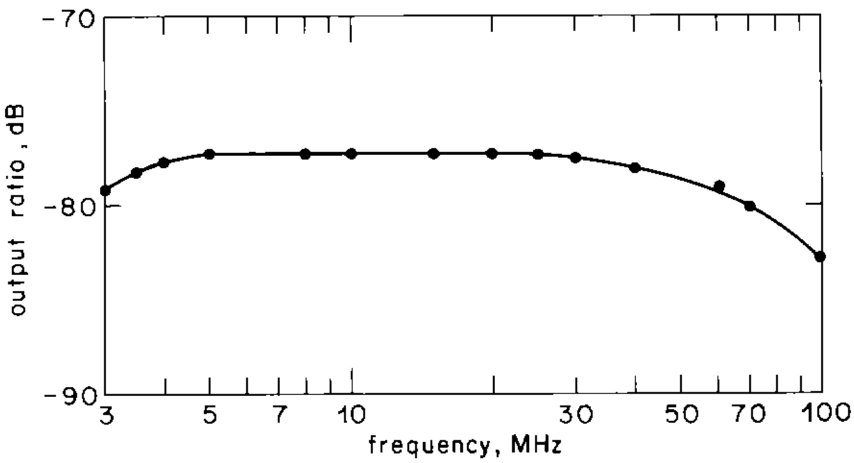



Fig. 9 — *Equalised unbalanced-mode coupler output ratio.*




and equalisers combination are shown in Figs. 8 and 9 respectively. The minimum directivity of the coupler is estimated to be not less than 26 dB over the 4-26 MHz Band.

## 8. Power tests at Rampisham h.f. transmitting station

At Rampisham the baseplate has been fitted to the trunking feeding the soda test load and because of bends and inaccessibility of parts of the trunking, it has been fitted some distance from the actual load in an area outside the transmitter building. A fairly long feeder run (18.3 m) has been necessary to bring the output from the unit into the transmitter building and as a consequence, this produces an attenuation slope on the output characteristic of the unit.

A measurement of forward power at 6.9 MHz was made and gave exact agreement with that deduced from the soda load calibration. Subsequently, the unit has been in use for a period of one year and has been found to give a satisfactory performance at all frequencies within its working bandwidth.

## 9. Conclusions

A reflectometer unit has been developed for monitoring purposes on a 500 kW, shielded, transmission line. It has successfully withstood the full sender output power without breakdown. The unit has a directivity of at least 34 dB in the main balanced mode and should permit reasonably simple measurement of the load applied to the transmitters.

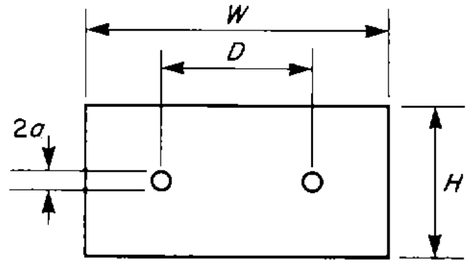
## 10. References


1. THODAY, R.D.C., LYNER, A.G. Reflectometer Units for Short-wave Senders. Research Department Report No. 1972/8.

2. FRANKEL, S. Characteristic Impedance of Parallel Wires in Rectangular Troughs. Proc. I.R.E. Vol. **30**, April 1942.

## 11. Appendix

*Fig. 10 – Screened twin conductor transmission line.*




The characteristic impedance $Z_o$ of the screened twin-conductor transmission line, shown in Fig. 10, driven in the balanced mode is given by[2] :–

$$Z_{o\,\mathrm{bal}} = 276 \left[ \log_{10} \left\{ \frac{2H}{\pi a} \tanh \left( \frac{\pi D}{2H} \right) \right\} - \sum_{m=1}^{\infty} \log_{10} \left\{ \frac{1 + P^2}{1 - Q^2} \right\} \right]$$

where $P = \dfrac{\sinh\left(\frac{\pi D}{2H}\right)}{\cosh\left(\frac{\pi W \mathrm{m}}{2H}\right)}$ , $Q = \dfrac{\sinh\left(\frac{\pi D}{2H}\right)}{\sinh\left(\frac{\pi W \mathrm{m}}{2H}\right)}$

provided that $a \ll W$, $H$ and $D$

with the dimensions:–

$$\begin{cases} W = 762\ \mathrm{mm} \\ H = 375\ \mathrm{mm} \\ D = 380\ \mathrm{mm} \\ a = 14\ \mathrm{mm} \end{cases}$$

$$Z_{o\,\mathrm{bal}} = 321\Omega$$

Using similar techniques of conformal transformation and image methods it has been found that the characteristic impedance of the line driven in the unbalanced mode is:–

$$Z_{o\,\mathrm{unbal}} = 69 \left[ \log_{10} \left( \frac{2H}{\pi a} \coth \frac{\pi D}{2H} \right) + \left(-1\right)^{\mathrm{m}} \sum_{\mathrm{m}=1}^{\infty} \right.$$

$$\left. \log_{10} \left\{ \left( \coth \frac{\pi \mathrm{m} W}{2H} \right)^2 \left( \coth \frac{\pi}{2H} \left( \mathrm{m}W + D \right) \right) \left( \coth \frac{\pi}{2H} \left( \mathrm{m}W - D \right) \right) \right\} \right]$$

For the dimensions give above

$$Z_{o\ \mathrm{unbal}} = 84.8\Omega$$

This is in good agreement with the figure obtained from the reflection coefficient measured while the line was driven unbalanced and terminated with a 50Ω load.

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